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INTERFEROMETER TUNABLE IN A NON-MECHANICAL MANNER BY A PANCHARATNAM PHASE

FIELD OF THE INVENTION

The present invention relates to an interferometer, in particular for the measurement of optical surfaces ~~according to the preamble of claim 1~~.

BACKGROUND INFORMATION

A conventional two-beam interferometer is used to measure optical surfaces by generating at the output an interference fringe pattern of the optical surface and, for example, supplying the pattern to a video camera for further processing. The light reflected by the optical surface, known also as a test wave field, contains aberrations because of lens defects and surface roughness at the surface to be measured, the aberrations being imaged by the interference fringe pattern. The local position of the deviations of the interference fringe pattern from an ideal fringe pattern (e.g. parallel fringes) correlates with the local position of the aberration in the test wave field and thus with the deviations of the optical test surface, for example, with respect to an ideally flat surface. Such a displacement of the interference fringe pattern because of aberrations may have a considerably adverse effect on the measuring sensitivity, because the fringe deformation, e.g., in the fringe maxima and minima, is not able to image the deformation of the test wave field as sensitively as in the regions with high intensity gradients. Therefore, it is desirable to be able to displace the interference fringe pattern in a defined manner, in order to improve the measuring accuracy. For this purpose, until now the reference surface or the test object itself has been moved or tilted in order to introduce an additional phase gradient into the interference beams and thus into the interference fringe pattern. In this manner it is also

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possible to obtain clear-cut information about the aberration of the test wave field, this subsequently allowing the elimination of defects, e.g. in a flat test surface. However, the movement of large and heavy test objects or reference surfaces introduces further inaccuracies into the interferometer.

SUMMARY

~~Therefore, the~~ An object of the present invention is to ~~create~~ provide an improved interferometer which does not require a drive mechanism for moving a reference surface or test object in order to tune the interferometer, and which can be tuned in virtually vibration-free manner, thereby preventing measuring errors.

~~The objective of the invention is achieved by the features of claim 1.~~

~~Advantageous further developments are outlined in the subclaims.~~

The present invention provides ~~The central thought behind the invention is to make available~~ a tunable interferometer without it being necessary for the reference surface or test object to be moved in order to tune the interferometer. Usually, the tuning of an interferometer is understood to mean the changing of the optical path of one arm of the interferometer by moving or tilting the reference surface or test object, this introducing a defined phase into the interferometer. In contrast, tuning within the meaning of the invention means that a defined phase, the so-called Pancharatnam phase, is introduced into the interferometer, there being, however, no change in the relative position between the reference surface and the test object. The phenomenon of the Pancharatnam phase is ~~known and is~~ described in detail in the paper

"*Pancharatnams Phase in Polarization Optics*", published in Advanced Electromagnetism, T. Barratt et al., Editors Singapore, pages 357-375 by W. Dultz et al.

The interferometer according to the present invention includes at least one light source, a reference surface and a test object, as well as at least one beam splitter. The interferometer further ~~contains~~ includes an apparatus for the polarization of the interference beams, such that they each have a different polarization state at the output of the interferometer. Disposed at the output of the interferometer is an analyzer with a polarization state, variable in predetermined manner, for tuning the interferometer. Depending on the polarization state of the analyzer, an additional phase, the "Pancharatnam phase", is introduced into the interference beams of different polarizations, the result being that the interference fringe pattern, imaging the test object, is displaced by a predetermined distance.

A linear relationship between the extent of displacement of the fringe pattern and the position of the analyzer is obtained when ~~if~~, in a two-beam interferometer, the interference beams are polarized orthogonally with respect to each other. This is achieved in that, first of all, a linearly polarized light, preferably laser light, is present at the input of the interferometer, and in that the polarization apparatus includes a first $\lambda/4$ retardation plate, allocated to the reference surface or to the test object, and a second $\lambda/4$ retardation plate, positioned before the analyzer. The first retardation plate ensures that the light beams reflected by the reference surface and by the test object are polarized orthogonally with respect to each other. The second retardation plate converts the two beams into a left-

circularly polarized beam and a right-circularly polarized beam.

The analyzer may be a rotatable linear analyzer or an electrically tunable liquid-crystal element with a linear polarizer.

In order to afford the interferometer additional protection against vibration during tuning, the interferometer and the analyzer may be physically separate, i.e., even installed at different locations.

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~~Following, the invention is described in greater detail with reference to an exemplary embodiment in conjunction with the Figure.~~

The Figure shows a two-beam interferometer 10, at whose input a linearly polarized laser light impinges which has previously passed through a linear polarizer 20. Subsequent to linear polarizer 20 is a beam conventional splitter 30~~, known per se,~~ which splits the incident light into at least two components. In the present example, a reference surface 40 is placed in the optical ray path which passes beam splitter 30. With reference to the light beam passing through beam splitter 30, there is an optical test object 50 after reference surface 40. Assume, for example, ~~Let it be assumed~~ that reference surface 40 is a flat glass plate having the characteristic that it transmits 95% of the incident light and reflects 5% of the incident light back to beam splitter 30. In the present example, test object 50 is likewise represented by a glass plate which, in turn, reflects 5% of the incident light and transmits 95% thereof. Disposed between reference surface 40 and test object 50 is a λ/4 plate 60, hereinafter referred to as retardation plate 60 for the sake of simplicity. ~~It must~~

The ~~be emphasized that the~~ described relative position between reference surface 40, retardation plate 60 and the test object serves merely as an example. A second $\lambda/4$ plate 70, hereinafter referred to as retardation plate 70 for the sake of simplicity, is disposed in interferometer 10 in such a manner that the light beams reflected by reference surface 40 and test object 50 and deflected by beam splitter 30 are able to pass through retardation plate 70. A rotatable linear analyzer 80 is arranged downstream of retardation plate 70, so that the interference beams passing through retardation plate 70 strike on analyzer 80. Downstream of analyzer 80 is, for example, a video camera (not shown) which records the interference fringe pattern supplied by interferometer 10 at the output.

The ~~In the following, the~~ mode of operation for tuning interferometer 10 is described in greater detail below. It must be emphasized once again that when tuning conventional interferometers ~~are tuned~~, ~~in that~~ reference surface 40 or test object 50 must be moved or tilted. However, interferometer 10 according to the present invention can be tuned without it being necessary to move reference surface 40 or the test object. In other words, the relative position between reference surface 40 and test object 50 remains unchanged. This is achieved by the present invention in that the interference beams, i.e., the beams reflected by reference surface 40 and test object ~~surface~~ 50, have different polarization states. Assume ~~Let it now be assumed~~ that the light traversing linear polarizer 20 is polarized in the direction of the arrow, i.e., vertically. The vertically polarized light strikes beam splitter 30 and half of it, for example, is reflected to the outside, the other half penetrating beam splitter 30. The vertically polarized light first strikes on reference surface 40, at which 5%

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of the light is reflected. The portion penetrating reference surface 40 ~~50~~ passes through retardation plate 60, as a result of which the vertically polarized light undergoes a right-circulating polarization. If this light falls on test object ~~surface~~ 50, the reflected light is then left-circularly polarized. The light reflected at test surface 50 passes through retardation plate 60 again. Having again traversed retardation plate 60, the light once again has a linear polarization which, however, is orthogonal with respect to the polarization of the light reflected at reference surface 40. The two reflected interference beams with polarizations that are orthogonal relative to each other strike, in turn, on beam splitter 30 which deflects half of the light intensity onto retardation plate 70. In retardation plate 70, the two interference beams undergo circular polarization, one of the beams being right-circularly polarized and the other being left-circularly polarized. Owing to this polarization state of the interference beams and the rotatable linear analyzer 80, there is a linear relationship between the displacement of the interference fringe pattern at the output of interferometer 10, and the rotational angle of linear analyzer 80. In order to tune interferometer 10, linear analyzer 80 is simply rotated in a predetermined manner, whereby the "Pancharatnam phase" is introduced into interferometer 10, the Pancharatnam phase causing the linear displacement of the interference fringe pattern. The rotation angle by which linear analyzer 80 must be rotated in order to cause a predetermined displacement of the interference fringe pattern can be accurately determined if use is made of the Poincaré sphere, which ~~is known per se~~. The polarization states of the interference beams are on the poles of the Poincaré sphere, linear analyzer 80 moving on the equator when it

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is rotated. The phase which in this manner is inserted into interferometer 10 is $\lambda=\frac{1}{2}\,\Omega(A, R, L, P)$ when Ω is the spherical excess of the spherical lune A, R, P, L, A on the Poincaré sphere. Therein, A is the linear polarization state of the light at the input of interferometer 10. R and L, respectively, stand for the right- and left-circulating polarization states of the two interference beams. The right- R and left- L circulating polarization states of the two interference beams are achieved, as described above ~~already mentioned~~, by retardation plates 60 and 70. The right- and left-circularly polarized light (R, L) is, as described above ~~already mentioned~~, present at the output of retardation plate 70. With the aid of rotatable linear analyzer 10, the Pancharatnam phase λ, which is proportional to the rotational angle of analyzer 80, is introduced between the left- and right-circularly polarized beams at the output of the interferometer. Through the defined rotation of analyzer 80, the Pancharatnam phase is changed in predetermined manner, and the interference fringes, recorded by the video camera, are displaced as if reference surface 40 or test surface 50 had been displaced. Instead of a rotatable linear analyzer 80, it is possible to employ a conventional ~~an~~ electrically tunable liquid-crystal element~~, known per se,~~ with a linear polarizer. Particularly advantageous ~~preferred~~ is an electrically rotatable $\lambda/2$ retardation plate of the kind producible using modern liquid-crystal techniques. With such retardation plates, which operate very quickly, the axial orientation is rotated with the electric voltage.

Interferometer 10 can be tuned with all processes in which the two beams are differently polarized. However, the tuning is only linear, i.e., calculable, if the polarizations of the beams reflected at reference surface 40 and test object 50 are orthogonal and if the analyzer

moves on the symmetrically intermediate great circle on the Poincaré sphere.